STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2015/2016

ENT2016 – SOLID STATE ELECTRONICS
(Nano)

12 MARCH 2016
2.30 p.m - 4.30 p.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.

2. Attempt all **FOUR** questions. The distribution of the marks for each question is given.

3. Please print all your answers in the Answer Booklet provided.

Question 1

(a) Briefly explain the difference between a primitive cell and a unit cell. What are the functions of both concepts?

[3 marks]

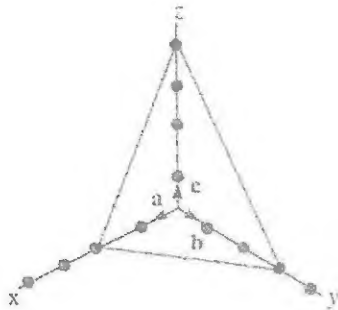(b) Label the planes illustrated in Figure Q1 (b)-(i) and (b)-(ii).

Figure Q1 (b)-(i)   Figure Q1 (b)-(ii)
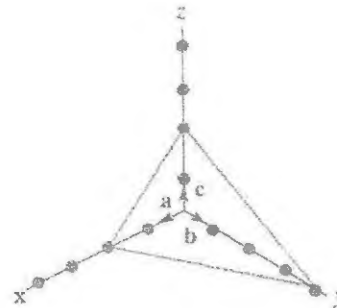
[3 marks]

(c) Consider a body centered cubic (BCC) unit cell with a mono-atomic basis having an atomic density of the unit cell equivalent to 1.6×10^{22} cm^{-3},

    (i) Sketch the BCC unit cell with mono-atomic basis. [2 marks]

    (ii) Calculate the lattice constant. [3 marks]

    (iii) Calculate is the atomic density per unit area on the (110) plane. [3 marks]

    (iv) Find the nearest neighbor atomic distance for this cell. [2 marks]

    (v) Determine the radius of each atom. [1 marks]

(d) Polysilicon is composed of many grains (or small crystals) orientated in different directions. Explain briefly why impurities can diffuse easily along the grain boundaries. [3 marks]

(e) Calculate the densities of Si and GaAs, provided that the atomic weights of Si, Ga, and As are 28.1, 69.7, and 74.9, respectively.

[5 marks]

Continued...

Question 2

(a)   With the aid of suitable diagrams, briefly describe the following:

    (i)   Interstitial impurity of atom   [2 marks]
    (ii)   Vacancy defect in crystal structure   [2 marks]

(b)   Briefly explain with examples the chemisorption and the physisorption processes that might occur at a crystal surface.

[4 marks]

(c)   The potential energy E per Cs^+-Cl^- pair within the CsCl crystal depends on the interionic separation r in the same fashion as in the NaCl crystal,

$$E(r) = -\frac{e^2 M}{4\pi\varepsilon_o r} + \frac{B}{r^m}$$

Where,
for CsCl, $M = 1.763$, $B = 1.192\times10^{-104}$ J m^9 or 7.442×10^{-5} eV (nm)^9 and $m = 9$.

    (i)   Find the equilibrium separation (r_o) of the ions in the crystal

[5 marks]

    (ii)   Find the ionic bonding energy, that is, the ionic cohesive energy; Compare the ionic bonding energy value to the experimental value of 657 kJ mol^{-1}. Given the ionization energy of Cs is 3.89 eV and the electron affinity of Cl (energy released when an electron is added) is 3.61 eV.

[7 marks]

    (iii)   Calculate the atomic cohesive energy of the CsCl crystal in joules per mole.

[3 marks]

(d)   In Sodium chloride, impurity Ca^{2+} and O^{2-} ions would most likely substitute Na^+ and Cl^- ions, respectively. Suggest two possibilities to preserve electroneutrality. If electroneutrality is to be preserved, identify the types of point defects that are possible in NaCl when a Ca^{2+} substitutes for an Na^+ ion?

[2 marks]

Continued...

Question 3

(a)   Briefly explain the Compton scattering of electron.

[5 marks]

(b)   Give examples to illustrate that electromagnetic radiation exhibits wave-particle duality.

[3 marks]

(c)   Classical physics cannot explain **three** of the main results of photoelectric-effect experiment as shown in the Figure Q3(c). What are these three experiment results? Use diagram to support your answers.
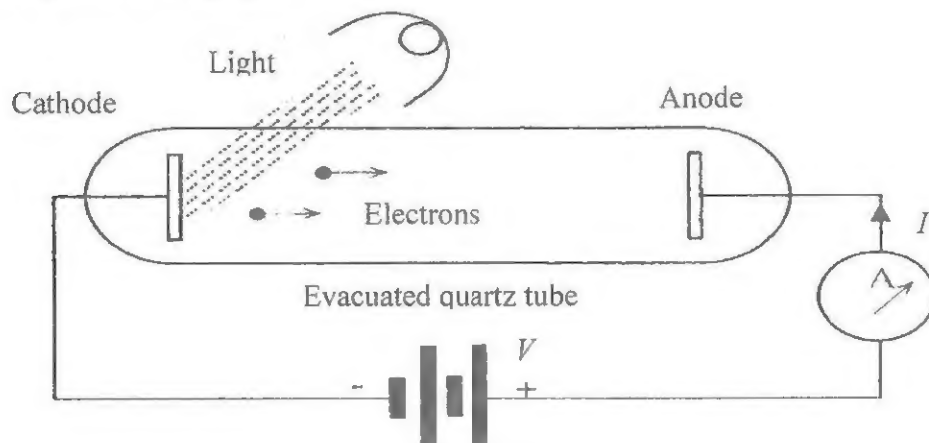

Figure Q3(c)

[6 marks]

(d)   Show that if the uncertainty in the position of a particle is on the order of its de Broglie wavelength, then the uncertainty in its momentum is about the same as the momentum value itself.

[5 marks]

(e)   In a photoelectric effect experiment, the threshold wavelength for the ejection of photoelectrons from zinc is 310 nm. Calculate the work function for Zinc. Also, calculate the velocity for the photoelectrons by light of wavelength 2000 Å other than threshold.

[6 marks]

Continued...

Question 4

(a) Briefly describe the following:

     (i)   Mean free path   [2 marks]

     (ii)   Mean relaxation time   [1 mark]

     (iii)   Matthiessen's Rule   [1 mark]

     (iv)   Kronig-Penney Model   [2 marks]

(b) Find the intrinsic carrier concentration in gallium arsenide at $T = 300$ K.

[4 marks]

(c) Consider silicon at $T = 300$ K so that $N_c = 2.8 \times 10^{19}$ cm^{-3} and $N_v = 1.04 \times 10^{15}$ cm^{-3}. Given that the bandgap energy of silicon is 1.12 eV and the Fermi energy is 0.25 eV below the conduction band.

     (i)   Calculate the thermal equilibrium concentrations of electrons

[2.5 marks]

     (ii)   Calculate the thermal equilibrium concentrations of holes

[2.5 marks]

(d) Calculate the probability that a state in the conduction band is occupied by an electron at $T = 300K$. Assume that the Fermi energy is 0.57 eV below the conduction band and the bandgap energy of Silicon is 1.42 eV.

[4 marks]

(e) An n-type silicon containing 5×10^{16} atoms cm^{-3} of phosphorous (P) at room temperature. Given kT is 0.0259 eV, the intrinsic carrier concentration (n_i) is 1.0×10^{10} cm^{-3}, the effective density of states in valence (N_v) and conduction (N_c) bands are 1.0×10^{19} cm^{-3} and 2.8×10^{19} cm^{-3}, respectively. Calculate ;

     (i)   Electron concentration

[1 mark]

     (ii) Hole concentration

[1 mark]

     (iii) Fermi energy level

[4 marks]

Continued...

Useful constants and materials properties:

Physical constants		
Boltzmann's constant	k	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant	h	6.626×10^{-34} J s
Thermal voltage @ 300 K	kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space	m_e	9.10939×10^{-31} kg
Electron charge	e	1.60218×10^{-19} C
Effective density of states in the conduction band (for Si)	N_c	2.8×10^{19} cm^{-3}
Effective density of states in the Valence band (for Si)	N_v	1.04×10^{19} cm^{-3}
Permeability of free space	μ_o	$4\pi \times 10^{-7}$ H/m
Permittivity of free space	ε_o	8.85×10^{-12} F/m
Avogadro's number	N_A	6.023×10^{23} mol^{-1}

Semiconductor Materials Properties at 300 k					
Materials	Energy gap	Intrinsic concentration	Electron mobility	Hole mobility	Dielectric Constant
Notations	E_g (eV)	n_i (cm^{-3})	μ_e (cm^2 V^{-1} s^{-1})	μ_h (cm^2 V^{-1} s^{-1})	ε_r
Si	1.10	1×10^{10}	1350	450	11.7
GaAs	1.42	2.1×10^{6}	8500	400	13.1
Ge	0.66	2.3×10^{13}	3900	1900	16

End of Paper